NCHRP 9-29 Equipment Specification for Simple Performance Test System Version 3.0

NCHRP Project 9-29

Simple Performance Tester for Superpave Mix Design

Equipment Specification For The Simple Performance Test System

October 16, 2007

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1.0 Summary

1.1 This specification describes the requirements for a testing system to conduct the following National Cooperative Highway Research Program (NCHRP) Project 9-19 simple performance tests:

Test Method For Static Creep/Flow Time of Asphalt Concrete Mixtures in Compression

Test Method for Repeated Load Testing of Asphalt Concrete Mixtures in Uniaxial Compression

Test Method for Dynamic Modulus of Asphalt Concrete Mixtures for Permanent Deformation

Test Method for Dynamic Modulus of Asphalt Concrete Mixtures for Fatigue Cracking

Note: This equipment specification represents a revision of the equipment requirements contained in NCHRP Report 465 and AASHTO TP62. The requirements of this specification supersede those contained in NCHRP Report 465 and AASHTO TP62.

1.2 The testing system shall be capable of performing three compressive tests on nominal 100 mm (4 in) diameter, 150 mm (6 in) high cylindrical specimens. The tests are briefly described below.

1.3 **Flow Time Test.** In this test, the specimen is subjected to a constant axial compressive load at a specific test temperature. The test may be conducted with or without confining pressure. The resulting axial strain is measured as a function of time and numerically differentiated to calculate the flow time. The flow time is defined as the time corresponding to the minimum rate of change of axial strain. This is shown schematically in Figure 1.

1.4 **Flow Number Test.** In this test, the specimen, at a specific test temperature, is subjected to a repeated haversine axial compressive load pulse of 0.1 sec every 1.0 sec. The test may be conducted with or without confining pressure. The resulting permanent axial strains are measured as a function of time and numerically differentiated to calculate the flow number. The flow number is defined as the number of load cycles corresponding to the minimum rate of change of permanent axial strain. This is shown schematically in Figure 2.

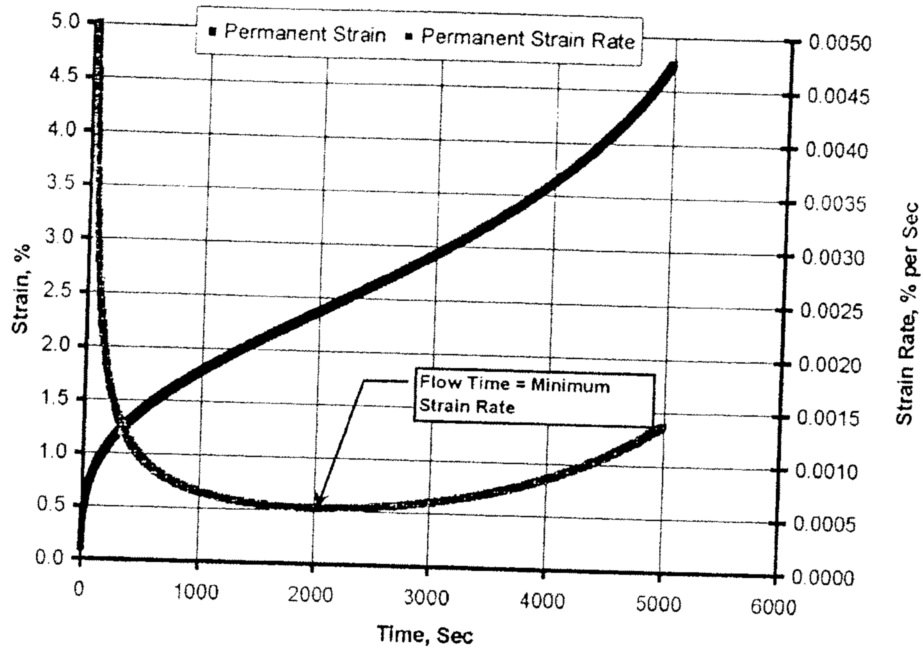

Figure 1. Schematic of Flow Time Test Data.

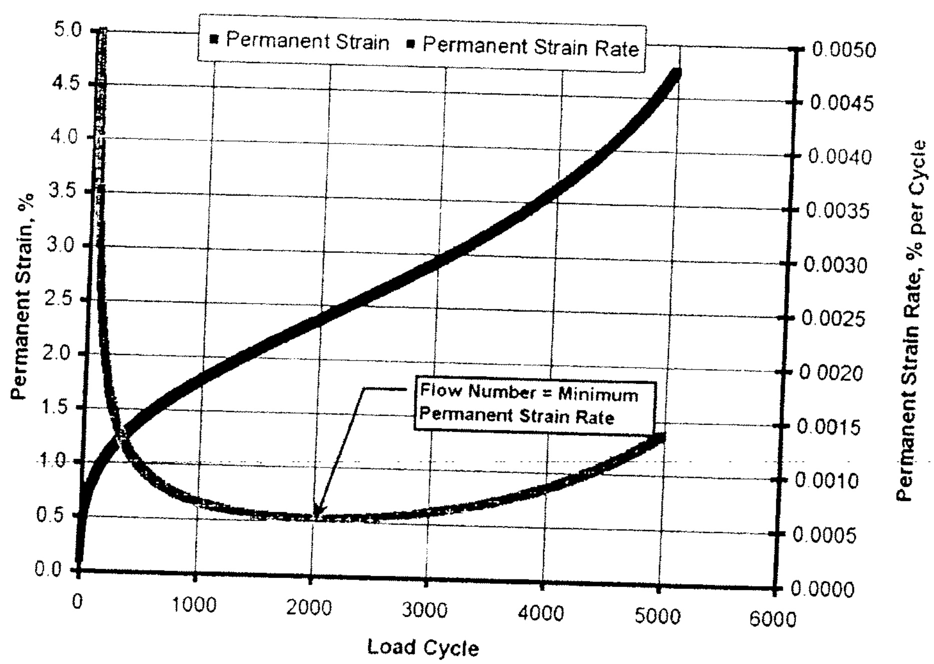

Figure 2. Schematic of Flow Number Test Data.

1.5 **Dynamic Modulus Test.** In this test, the specimen, at a specific test temperature, is subjected to controlled sinusoidal (haversine) compressive stress of various frequencies. The applied stresses and resulting axial strains are measured as a function of time and used to calculate the dynamic modulus and phase angle. The dynamic modulus and phase angle are defined by Equations 1 and 2. Figure 3 presents a schematic of the data generated during a typical dynamic modulus test.

$$|E^*| = \frac{\sigma_o}{\varepsilon_o} \tag{1}$$

$$\phi = \frac{T_i}{T_p}(360) \tag{2}$$

Where:

$|E^*|$ = dynamic modulus
ϕ = phase angle, degree
σ_o = stress amplitude
ε_o = strain amplitude
T_i = time lag between stress and strain
T_p = period of applied stress

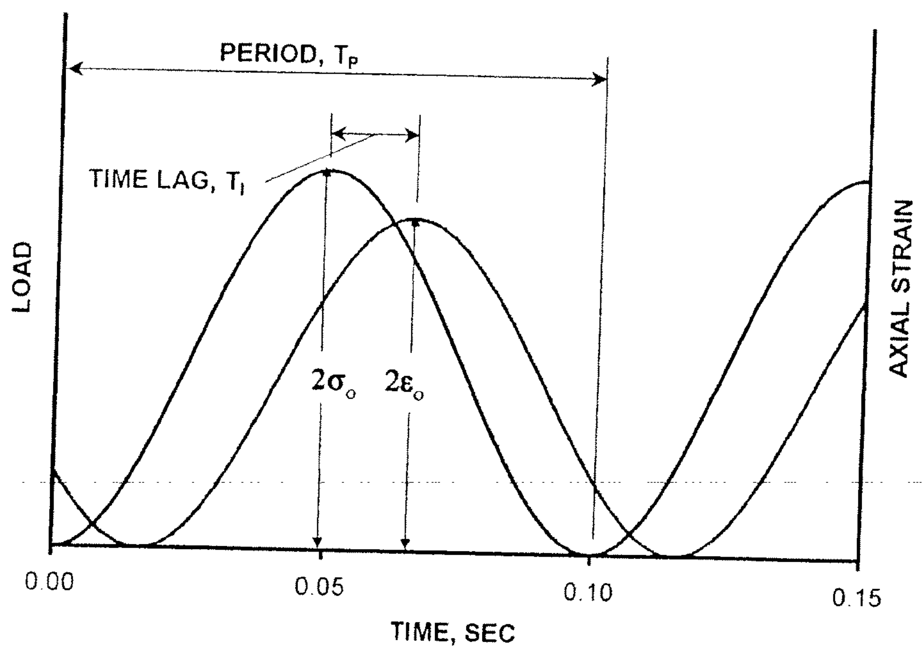

Figure 3. Schematic of Dynamic Modulus Test Data.

2.0 Definitions

2.1 *Flow Time.* Time corresponding to the minimum rate of change of axial strain during a creep test.

2.2 *Flow Number.* The number of load cycles corresponding to the minimum rate of change of permanent axial strain during a repeated load test.

2.3 *Dynamic Modulus.* Ratio of the stress amplitude to the strain amplitude for asphalt concrete subjected to sinusoidal loading (Equation 1).

2.4 *Phase Angle.* Angle in degrees between a sinusoidally applied stress and the resulting strain in a controlled stress test (Equation 2).

2.5 *Resolution.* The smallest change of a measurement that can be displayed or recorded by the measuring system. When noise produces a fluctuation in the display or measured value, the resolution shall be one-half of the range of the fluctuation.

2.6 *Accuracy.* The permissible variation from the correct or true value.

2.7 *Error.* The value obtained by subtracting the value indicated by a traceable calibration device from the value indicated by the measuring system.

2.8 *Confining Pressure.* Stress applied to all surfaces in a confined test.

2.9 *Deviator Stress.* Difference between the total axial stress and the confining pressure in a confined test.

2.10 *Dynamic Stress.* Sinusoidal deviator stress applied during the Dynamic Modulus Test.

2.11 *Dynamic Strain.* Sinusoidal axial strain measured during the Dynamic Modulus Test.

3.0 Test Specimens

3.1 Test specimens for the Simple Performance Test System will be cylindrical meeting the following requirements:

	Item	Specification	Note
Specimen Dimensions	Average Diameter	100 mm to 104 mm	1
	Standard Deviation of Diameter	0.5 mm	1
	Height	147.5 mm to 152.5 mm	2
	End Flatness	0.5 mm	3
	End Perpendicularity	1.0 mm	4

Notes:	1. Using calipers, measure the diameter at the center and third points of the test specimen along axes that are 90 ° apart. Record each of the six measurements to the nearest 0.1 mm. Calculate the average and the standard deviation of the six measurements. 2. Measure the height of the test specimen in accordance with Section 6.1.2 of ASTM D 3549. 3. Using a straightedge and feeler gauges, measure the flatness of each end. Place a straight edge across the diameter at three locations approximately 120 ° apart and measure the maximum departure of the specimen end from the straight edge using tapered end feeler gauges. For each end record the maximum departure along the three locations as the end flatness. 4. Using a combination square and feeler gauges, measure the perpendicularity of each end. At two locations approximately 90 ° apart, place the blade of the combination square in contact with the specimen along the axis of the cylinder, and the head in contact with the highest point on the end of the cylinder. Measure the distance between the head of the square and the lowest point on the end of the cylinder using tapered end feeler gauges. For each end, record the maximum measurement from the two locations as the end perpendicularity.

4.0 Simple Performance Test System

4.1 The Simple Performance Test System shall be a complete, fully integrated testing system meeting the requirements of these specifications and having the capability to perform the Flow Time, Flow Number, and Dynamic Modulus tests.

4.2 Appendix A summarizes the methods that will be used to verify that the Simple Performance Test System complies with the requirements of this specification.

4.3 The Simple Performance Test System shall include the following components:

1. Compression loading machine.
2. Loading platens.
3. Load measuring system.
4. Deflection measuring system.
5. Specimen deformation measuring system.
6. Confining pressure system.
7. Environmental chamber.
8. Computer control and data acquisition system.

4.4 The load frame, environmental chamber, and computer control system for the Simple Performance Test System shall occupy a foot-print no greater than 1.5 m (5 ft) by 1.5 m (5 ft) with a maximum height of 1.8 m (6 ft). A suitable frame, bench or cart shall be provided so that the bottom of the test specimen, and the computer keyboard and display are approximately 90 cm (36 in) above the floor.

4.5 The load frame, environmental chamber and computer control system for the Simple Performance Test System shall operate on single phase 115 or 230 VAC 60 Hz electrical power.

4.6 If a hydraulic power supply is required, it shall be air-cooled occupying a foot-print no larger than 1 m (3 ft) by 1.5 m (5 ft). The noise level 2 m (6.5 ft) from the hydraulic power supply shall not exceed 70 dB. The hydraulic power supply shall operate on single phase 115 of 230 VAC 60 Hz electrical power.

4.7 When disassembled, the width of any single component shall not exceed 76 cm (30 in)

4.8 Air supply requirements shall not exceed 0.005 m^3/s (10.6 ft^3/min) at 850 kPa (125 psi).

4.9 The Simple Performance Test System shall include appropriate limit and overload protection.

4.10 An emergency stop shall be mounted at an easily accessible point on the system.

5.0 Compression Loading Machine

5.1 The machine shall have closed-loop load control with the capability of applying constant, ramp, sinusoidal, and pulse loads. The requirements for each of the simple performance tests are listed below.

Test	Type of Loading	Capacity	Rate
Flow Time	Ramp, constant	10 kN (2.25 kips)	0.5 sec ramp
Flow Number	Ramp, constant, pulse	8 kN (1.80 kips)	10 Hz pulse with 0.9 sec dwell
Dynamic Modulus	Ramp, constant, sinusoidal	13.5 kN (3.0 kips)	0.01 to 25 Hz

5.2 For ramp and constant loads, the load shall be maintained within +/- 2 percent of the desired load.

5.3 For sinusoidal loads, the standard error of the applied load shall be less than 5 percent. The standard error of the applied load is a measure of the difference between the measured load data, and the best fit sinusoid. The standard error of the load is defined in Equation 3.

$$se(P) = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \hat{x}_i)^2}{n-4}}\left(\frac{100\%}{\hat{x}_o}\right) \tag{3}$$

Where:

$se(P)$ = Standard error of the applied load
x_i = Measured load at point i
$\hat{x}_i$ = Predicted load at point i from the best fit sinusoid, See Equation 14
$\hat{x}_o$ = Amplitude of the best fit sinusoid
n = Total number of data points collected during test.

5.4 For pulse loads, the peak of the load pulse shall be within +/- 2 percent of the specified value and the standard error of the applied load during the sinusoidal pulse shall be less than 10 percent.

5.5 For the Flow Time and Flow Number Tests, the loading platens shall remain parallel during loading. For the Dynamic Modulus Test, the load shall be applied to the specimen through a ball or swivel joint.

6.0 Loading Platens

6.1 The loading platens shall be fabricated from aluminum and have a Brinell Hardness Number HBS 10/500 of 95 or greater.

6.2 The loading platens shall be at least 25 mm (1 in) thick. The diameter of the loading platens shall not be less than 105 mm (4.125 in) nor greater than 108 mm (4.25 in).

6.3 The loading platens shall not depart from a plane by more than 0.0125 mm (0.0005 in) across any diameter.

7.0 Load Measuring System

7.1 The Simple Performance Test System shall include an electronic load measuring system with full scale range equal to or greater than the stall force for the actuator of the compression loading machine.

7.2 The load measuring system shall have an error equal to or less than +/- 1 percent for loads ranging from 0.12 kN (25 lb) to 13.5 kN (3.0 kips) when verified in accordance with ASTM E4

7.3 The resolution of the load measuring system shall comply with the requirements of ASTM E4.

8.0 Deflection Measuring System

8.1 The Simple Performance Test System shall include a electronic deflection measuring system that measures the movement of the loading actuator for use in the Flow Time and Flow Number Tests

8.2 The deflection measuring system shall have a range of at least 12 mm (0.5 in).

8.3 The deflection measuring system shall have a resolution equal to or better than 0.0025 mm (0.0001 in).

8.4 The deflection measuring system shall have an error equal to or less than 0.03 mm (0.001 in) over the 12 mm range when verified in accordance with ASTM D 6027.

8.5 The deflection measuring system shall be designed to minimize errors due to compliance and/or bending of the loading mechanism. These errors shall be less than 0.25 mm (0.01 in) at 8 kN (1.8 kips) load.

9.0 Specimen Deformation Measuring System

9.1 The Simple Performance Test System shall include a glued gauge point system for measuring deformations on the specimen over a gauge length of 70 mm (2.76 in) ± 1 mm (0.04 in) at the middle of the specimen. This system will be used in the Dynamic Modulus Test, and shall include at least two transducers spaced equally around the circumference of the specimen.

9.2 Figure 4 shows a schematic of the standard specimen deformation measuring system with critical dimensions. Other properties of the deformation measuring system are listed below.

Property	Value
Gauge point contact area	80 mm^2 ± 10 mm^2
Dimension of the gauge point in the direction of the guage length	10 mm ± 1 mm
Mass of mounting system and transducer	80 g max
Transducer spring force	1 N max

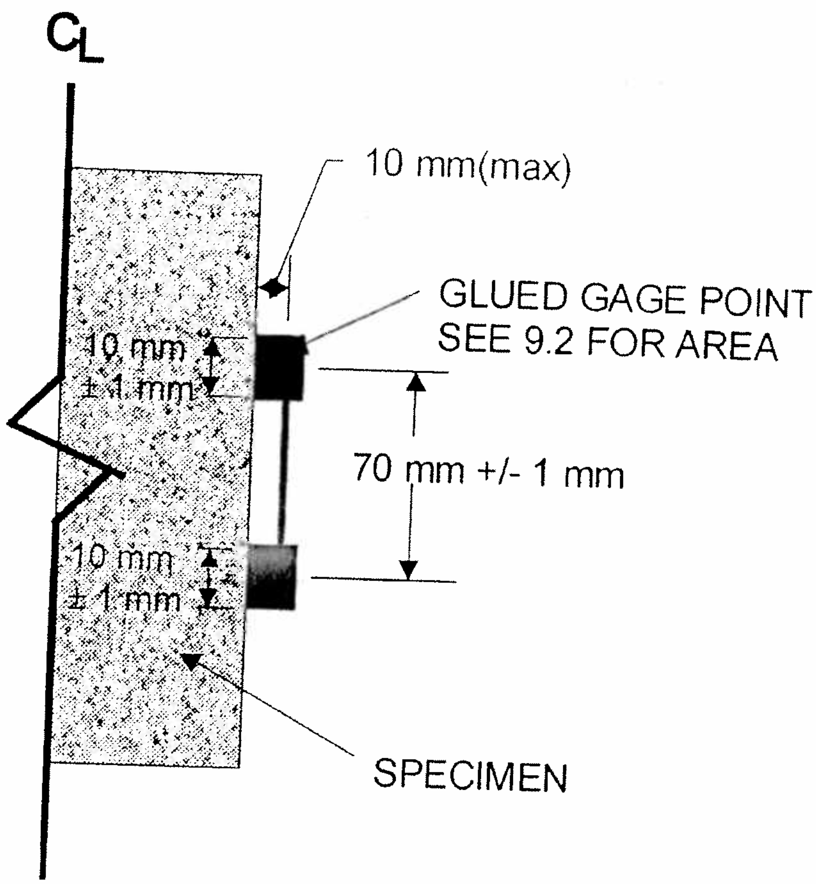

Figure 4. Schematic of Standard Specimen Mounted Deformation Measuring System.

9.3 The transducers shall have a range of at least 1 mm (0.04 in).

9.4 The transducers shall have a resolution equal to or better than 0.0002 mm (7.8 micro inch).

9.5 The transducers shall have an error equal to or less than 0.0025 mm (0.0001 in) over the 1 mm range when verified in accordance with ASTM D 6027.

9.6 The axial deformation measuring system shall be designed for rapid specimen installation and subsequent testing. Specimen instrumentation, installation, application of confining pressure, and temperature equilibration shall take no longer than 5 minutes over the complete range of temperatures.

9.7 Alternatives to the standard system described in this section will be considered provided the components meet the range, accuracy, and resolution requirements. Submit data showing the alternative system produces the same modulus and phase angles as the standard system on asphalt concrete specimens tested over the stiffness range of 150 to 10,000 MPa (20,000 to 2,200,000 psi). Appendix B describes the minimum testing and analysis required for a non-standard system.

10.0 Confining Pressure System

10.1 The confining pressure system shall be capable of providing a constant confining pressure up to 210 kPa (30 psi) to the test specimen. The system shall include a pressure cell with appropriate pressure regulation and control, a flexible specimen membrane, a device or method for detecting leaks in the membrane, a pressure transducer, and a temperature sensing device that is mounted internal to the cell.

10.2 The confining pressure cell shall be designed to allow the operator to view the specimen, the specimen mounted deformation measuring system, and the specimen end platens during testing.

10.3 Confining pressure shall be controlled by the computer control and data acquisition system. The confining pressure control system shall have the capability to maintain a constant confining pressure throughout the test within +/- 2 percent of the desired pressure.

10.4 The specimen shall be enclosed in an impermeable flexible membrane sealed against the loading platens.

10.5 The pressure inside the specimen membrane shall be maintained at atmospheric pressure through vents in the loading platens. The system shall include a device or method for detecting membrane leaks.

10.6 The confining pressure system shall include a pressure transducer for recording confining pressure during the test. The pressure transducer shall have a range of at least 210 kPa, (30 psi) and a resolution of 0.5 kPa (0.07 psi). The pressure transducer shall have an error equal to or less than ±1 percent of the indicated value over the range of 35 kPa (5 psi) to 210 kPa (30 psi) when verified in accordance with ASTM D5720.

10.7 A suitable temperature sensor shall be mounted at the mid-height of the specimen in the pressure cell between the specimen and the cell wall. This temperature sensor shall have a range of 0 to 60 °C (32 to 140 °F), and be readable and accurate to the nearest 0.25 °C. (0.5 °F). For confined testss this sensor shall be used to control the temperature in the chamber, and provide a continuous reading of temperature that will be sampled by the data acquisition system during the test.

10.8 The confining pressure system shall be designed for rapid installation of the test specimen in the confining cell and subsequent equilibration of the chamber temperature to the target test temperature. Specimen instrumentation, installation, application of confining pressure, and temperature equilibration shall take no longer than 5 minutes over the complete range of temperatures.

11.0 Environmental Chamber

11.1 The environmental chamber shall be capable of controlling temperatures inside the chamber over the range from 4 to 60 °C (39 to 140 °F) within +/- 0.5 °C (1 °F), when room temperature is between 15 and 27 °C (60 and 80 °F).

11.2 The environmental chamber need only be large enough to accommodate the test specimen. It is envisioned that specimens will be preconditioned in a separate chamber that is large enough to hold the number of specimens needed for a particular project along with one or more dummy specimens with internally mounted temperature sensors.

11.3 The environmental chamber shall be designed to allow the operator to view the specimen, the specimen mounted deformation measuring system, and the specimen end platens during testing.

11.4 The environmental chamber shall be designed for rapid installation of the test specimen and subsequent equilibration of the environmental chamber temperature to the target test temperature. Specimen instrumentation, installation, application of confining pressure, and temperature equilibration shall take no longer than 5 minutes over the complete range of temperatures.

11.5 A suitable temperature sensor shall be mounted in the environmental chamber within 25 mm (1 in) of the specimen at the mid-height of the specimen. This temperature sensor shall have a range of 0 to 60 °C (32 to 140 °F), and be readable and accurate to the nearest 0.25 °C (0.5 °F). This sensor shall be used to control the temperature in the chamber, and provide a continuous reading of temperature that will be sampled by the data acquisition system during the test.

12.0 Computer Control and Data Acquisition

12.1 The Simple Performance Test System shall be controlled from a Personal Computer operating software specifically designed to conduct the Flow Time, Flow Number, and Dynamic Modulus Tests and to analyze data in accordance with Section 13.

12.2 The Simple Performance Test System Software shall provide the option for user selection of SI or US Customary units.

12.3 Flow Time Test Control and Data Acquisition

12.3.1 The control system shall control the deviator stress, and the confining pressure within the tolerances specified in Sections 5 and 10.2

12.3.2 The control system shall ramp the deviator stress from the contact stress condition to the creep stress condition in 0.5 sec.

12.3.3 Zero time for data acquisition and zero strain shall be defined as the start of the ramp from contact stress to creep stress. Using this time as a reference, the system shall provide a record of deviator stress, confining pressure, axial strain, and temperature at zero time and a user specified sampling interval, t, between (0.5 and 10 sec). The axial strains shall be based on the user provided specimen length and the difference in deflection at any time and the deflection at zero time.

12.3.4 The control system shall terminate the test and return the deviator stress and confining pressure to zero when the axial strain exceeds 5 percent or the maximum user specified test duration time is exceeded.

12.3.5 Figure 5 presents a schematic of the specified loading and data acquisition.

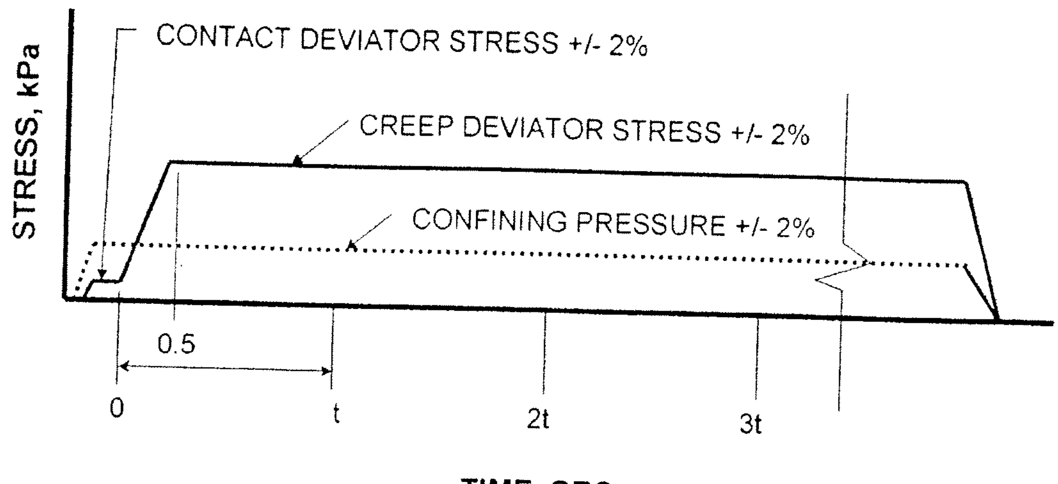

Figure 5. Schematic of Loading and Data Acquisition.

12.3.6 The Flow Time Test Software shall include a screen to input test and file information including:

1. Project Name
2. Operating Technician
3. Specimen Identification
4. File Name
5. Specimen Diameter
6. Specimen Height
7. Target Test Temperature
8. Target Confining Stress
9. Target Contact Deviator Stress
10. Target Creep Deviator Stress
11. Specimen Conditioning Time
12. Sampling Interval
13. Test Duration
14. Remarks

12.3.7 The Flow Time Test Software shall prompt the operator through the Flow Time Test.

1. Test and file information screen.
2. Insert specimen.
3. Apply confining pressure and contact stress.
4. Wait for temperature equilibrium, check for confining system leaks.
5. Ramp to creep stress, collect and store data.
6. Post test remarks.
7. Remove tested specimen.

12.3.8 During the creep loading portion of the test, the Flow Time Test Software shall provide a real-time display of the time history of the deviator stress abd the axial strain.

12.3.9 If at any time during the creep loading portion of the test, the deviator stress, confining pressure, or temperature exceed the tolerances listed below, the Flow Time Test Software shall display a warning and indicate the parameter that exceeded the control tolerance. The test shall continue and the software shall include this warning in the data file and the hard copy output.

Response	Tolerance
Deviator stress	+/- 2 percent of target
Confining pressure	+/- 2 percent of target
Temperature	+/- 0.5 °C of target

12.3.10 Data files shall include the following information:

1. Test information supplied by the user in Section 12.3.6.
2. Date and time stamp.
3. Computed flow time.
4. Sum of errors squared between measured and fitted axial strain.
5. Axial strain at the flow time.
6. Average temperature during the test.
7. Average confining stress during the test.
8. Time and corresponding measured deviator stress, measured confining pressure, measured temperature, measured axial strain, and computed rate of change of strain.
9. Warnings
10. Post test remarks.

12.3.11 The Flow Time Test Software shall provide the capability of retrieving data files and exporting them to an ASCII comma delimited file for further analysis.

12.3.12 The Flow Time Test Software shall provide a one page hard copy output with the following:

1. Test information supplied by the user in Section 12.3.6.
2. Date and time stamp.
3. Computed flow time.
4. Sum of errors squared between measured and fitted axial strain.
5. Axial strain at the flow time.
6. Average temperature during the test.
7. Average confining stress during the test.
8. Warnings

9. Post test remarks
10. Plot of measured axial strain versus time.
11. Plot of fitted axial strain versus time
12. Plot of rate of change of axial strain versus time with the flow time indicated.

12.4 Flow Number Test Control and Data Acquisition

12.4.1 The control system shall control the deviator stress, and the confining pressure within the tolerances specified in Sections 5 and 10.2

12.4.2 The control system shall be capable of applying an initial contact stress, then testing the specimen with the user specified cyclic deviator stress.

12.4.3 The data acquisition and control system shall provide the user the ability to select the sampling interval as a whole number of load cycles.

12.4.4 Zero deflection shall be defined as that at the start of the first load pulse. At the user specified sampling interval, the control system shall provide a record of peak deviator stress, standard error of the applied load (See Section 5.3), contact stress, confining pressure, permanent axial strain at the end of the load cycle, and temperature. The axial strains shall be based on the user provided specimen length and the difference in deflection the end of any load cycle and the zero deflection.

12.4.5 The control system shall terminate the test and return the deviator stress and confining pressure to zero when the axial strain exceeds 5 percent or the user specified test duration is reached.

12.4.6 The target and tolerance for the dwell time between load pulses are 0.9 ± 0.01 sec.

12.4.7 Figure 6 presents a schematic of the specified loading and data acquisition.

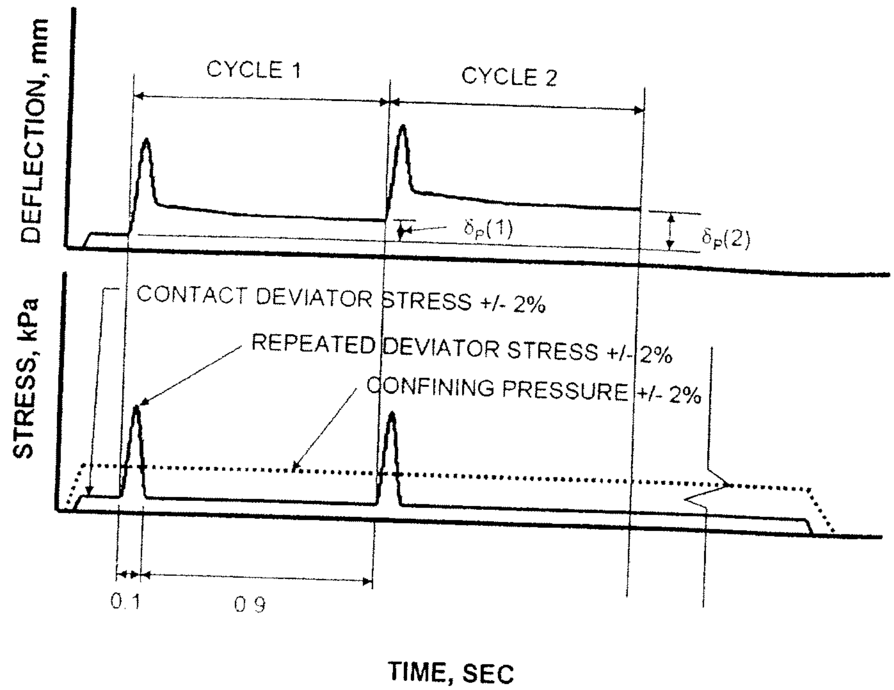

Figure 6. Schematic of Loading and Data Acquisition for Flow Time Test.

12.4.8 The Flow Number Test Software shall include a screen to input test and file information including:

1. Project Name
2. Operating Technician
3. Specimen Identification
4. File Name
5. Specimen Diameter
6. Specimen Height
7. Target Test Temperature
8. Target Confining Stress
9. Target Contact Deviator Stress
10. Target Repeated Deviator Stress
11. Specimen Conditioning Time
12. Sampling Interval
13. Maximum Number of Load Cycles
14. Remarks

12.4.9 The Flow Number Test Software shall prompt the operator through the Flow Number Test.

1. Test and file information screen.

2. Insert specimen.
3. Apply confining pressure and contact stress.
4. Wait for temperature equilibrium, check for confining system leaks.
5. Test specimen, collect and store data.
6. Post test remarks.
7. Remove tested specimen.

12.4.10 During the test, the Flow Number Test Software shall provide the user the ability to select the following displays and the ability to change between displays:

1. Digital oscilloscope showing stress and strain as a function of time.
2. A display of the history of the peak deviator stress, and permanent axial strain as a function of the number of load cycles.

12.4.11 If at any time during the test, the peak deviator stress, standard error of the applied load, confining pressure, temperature, or dwell time exceed the tolerances listed below, the Flow Number Test Software shall display a warning and indicate the parameter that exceeded the control tolerance. The test shall continue and the software shall include this warning in the data file and the hard copy output.

Response	Tolerance
Peak deviator stress	+/- 2 percent of target
Load standard error	10 percent
Confining pressure	+/- 2 percent of target
Temperature	+/- 0.5 °C of target
Dwell time	0.89 sec to 0.91 sec

12.4.12 Data files shall include the following information:

1. Test information supplied by the user in Section 12.4.7.
2. Date and time stamp.
3. Computed flow number.
4. Sum of errors squared between measured and fitted permanent axial strain.
5. Permanent axial strain at the flow number.
6. Average temperature during the test.
7. Average confining stress during the test.
8. Average peak deviator stress.
9. Average contact stress.
10. Maximum standard error of the applied load.
11. Cycle and corresponding measured peak deviator stress, computed load standard error, measured contact stress, measured confining pressure, measured temperature, measured permanent axial strain, and computed rate of change of permanent axial strain.

12. Warnings
13. Post test remarks.

12.4.13 The Flow Number Test Software shall provide the capability of retrieving data files and exporting them to an ASCII comma delimited file for further analysis.

12.4.14 The Flow Number Test Software shall provide a one page hard copy output with the following:

1. Test information supplied by the user in Section 12.4.7.
2. Date and time stamp.
3. Computed flow number.
4. Sum of errors squared between measured and fitted permanent axial strain.
5. Permanent axial strain at the flow number.
6. Average temperature during the test.
7. Average confining stress during the test.
8. Average peak deviator stress.
9. Average contact stress.
10. Maximum load standard error.
11. Warnings.
12. Post test remarks.
13. Plot of measured permanent axial strain versus load cycles.
14. Plot of fitted permanent axial strain versus load cycles.
15. Plot of rate of change of permanent axial strain versus load cycles with the flow number indicated.

12.5 Dynamic Modulus Test Control and Data Acquisition

12.5.1 The control system shall control the axial stress and the confining pressure. The confining pressure shall be controlled within the tolerances specified in Section 10.2.

12.5.2 The control system shall be capable of applying confining stress, an initial contact deviator stress, then conditioning and testing the specimen with a haversine loading at a minimum of 5 user selected frequencies.

12.5.3 Conditioning and testing shall proceed from the highest to lowest loading frequency. Ten conditioning and ten testing cycles shall be applied for each frequency.

12.5.4 The control system shall have the capability to adjust the dynamic stress and contact stress during the test to keep the average dynamic strain within the range of 85 to 115 μstrain. Adjustment of the dynamic stress shall be performed during the ten conditioning cycles at each loading frequency.

12.5.5 A contact stress equal to 5 percent of the dynamic stress shall be maintained during conditioning and testing.

12.5.6 During the 10 testing cycles, record and store the load, specimen deformations from the individual transducers, confining pressure, and temperature as a function of time. The data acquisition rate shall be set to obtain 50 data points per loading cycle.

12.5.7 The Dynamic Modulus Test Software shall include a screen to input test and file information including:

1. Project Name
2. Operating Technician
3. Specimen Identification
4. File Name
5. Specimen Diameter
6. Specimen Height
7. Target Test Temperature
8. Target Confining Stress
9. Loading Rates
10. Specimen Conditioning Time
11. Remarks

12.5.8 The Dynamic Modulus Test Software shall prompt the operator through the Dynamic Modulus Test.

1. Test and file information screen.
2. Insert specimen and attach strain instrumentation.
3. Apply confining pressure and contact stress.
4. Wait for temperature equilibrium, check for confining system leaks.
5. Condition and test specimen.
6. Review dynamic modulus, phase angle, temperature, confining pressure, and data quality statistics (See Section 13) for each frequency tested.
7. Post test remarks.
8. Remove tested specimen.

12.5.9 During the conditioning and testing, the Dynamic Modulus Test Software shall provide a real-time display of the axial stress, and the axial strain measured individually by the transducers.

12.5.10 If at any time during the conditioning and loading portion of the test, confining pressure, temperature, or average accumulated permanent strain exceed the tolerances listed below, the Dynamic Modulus Test Software shall display a warning and indicate the parameter that exceeded the control tolerance. The test shall continue and the software shall include this warning in the data file and the hard copy output.

Response	Tolerance
Confining pressure	+/- 2 percent of target
Temperature	+/- 0.5 °C of target
Permanent Axial Strain	0.0050 mm/mm

12.5.11 At the end of the user selected sweep of frequencies, the Dynamic Modulus Test software shall display a summary listing the following data for each frequency tested:

1. Dynamic modulus.
2. Phase angle.
3. Average temperature during the test.
4. Average confining pressure.
5. Data quality measures (See Section 13)
   - The drift for the applied load, ΔY_P, %
   - The standard error for the applied load, *se(P)*, %
   - The average drift for the deformations, $\Delta \bar{Y}_D$, %
   - The average standard error for the deformations, *se(Y)*, %
   - The uniformity coefficient for the deformations, U_A %
   - The uniformity coefficient for the deformation phase angles, U_θ, degrees.

The user should be provided options to save this data to data file and/or produce a hard copy output.

12.5.12 For each loading frequency, a separate data file shall be produced. This file shall include he test information supplied by the user in Section 12.5.7, a date and time stamp, and the following information:

1. Dynamic modulus.
2. Phase angle.
3. Strain amplitude
4. ~~Average temperature during the test.~~
5. Average confining pressure
6. Data quality measures (See Section 13)
   - The drift for the applied load, ΔY_P, %
   - The standard error for the applied load, *se(P)*, %
   - The average drift for the deformations, $\Delta \bar{Y}_D$, %
   - The average standard error for the deformations, *se(Y)*, %
   - The uniformity coefficient for the deformations, U_A %

- The uniformity coefficient for the deformation phase angles, U_θ, degrees.

7. Time and corresponding measured axial stress, individual measured axial strains, measured confining pressure, and measured temperature,
8. Warnings
9. Post test remarks.

12.5.13 The Dynamic Modulus Test Software shall provide the capability of retrieving data files and exporting them to an ASCII comma delimited file for further analysis.

12.5.14 For each loading frequency, the Dynamic Modulus Test Software shall provide a one page hard copy output with the following. Figure 7 presents an example one page output.

1. Test information supplied by the user in Section 12.5.7.
2. Date and time stamp.
3. Dynamic modulus.
4. Phase angle
5. Strain amplitude.
6. Average temperature during the test.
7. Average confining pressure during the test.
8. Data quality measures (See Section 13)
   - The drift for the applied load, ΔY_P, %
   - The standard error for the applied load, $se(P)$, %
   - The average drift for the deformations, $\Delta \bar{Y}_D$, %
   - The average standard error for the deformations, $se(\bar{Y})$, %
   - The uniformity coefficient for the deformations, U_A %
   - The uniformity coefficient for the deformation phase angles, U_θ, degrees.
10. Warnings
11. Post test remarks
12. Plot showing centered stress and centered strains as a function of time
13. Plot showing normalized stress and strains as a function of phase angle. This plot shall include both the measured and fit data.
14. Plot showing normalized stress as a function of normalized strain. This plot shall include both the measured and fit data.

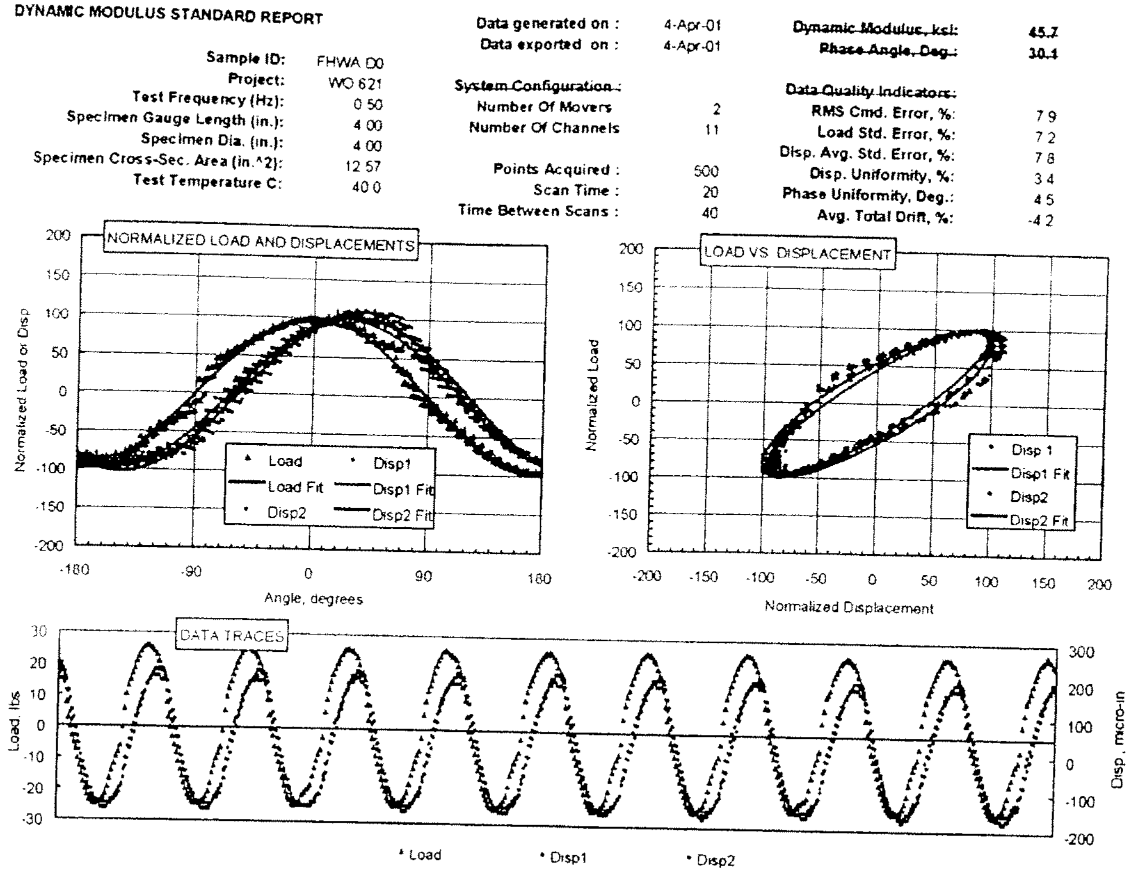

Figure 7. Example Dynamic Modulus Output.

13.0 Computations

13.1 Flow Time Test

13.1.1 The Flow Time is defined as the time corresponding to the minimum rate of change of axial strain during a creep test. The flow time is found by fitting the model described in Section 13.1.2 to the axial strain data using nonlinear least squares, then determining the inflection point from the second derivative of the model.

13.1.2 Axial strain model:

$$\varepsilon = At^B + C(e^{Dt} - 1) \tag{4}$$

where:

ε = axial strain
t = time
A, B, C, and D = fitting coefficients

13.1.3 First derivative (Strain Rate):

$$\frac{d\varepsilon}{dt} = ABt^{B-1} + CDe^{Dt} \tag{5}$$

13.1.4 Second derivative:

$$\frac{d^2\varepsilon}{dt^2} = AB(B-1)t^{B-2} + CD^2e^{Dt} \tag{6}$$

13.1.5 Fitting of Equation 4 shall produce a sum of squared errors between measured and fitted axial strain that is less than 0.5% when the strains are expressed in units of percent.

13.1.6 The Flow Time is reported as the time when the second derivative of the axial strain model, Equation 6, changes from negative to positive.

13.2 Flow Number Test

13.2.1 The Flow Number is defined as the cycle corresponding to the minimum rate of change of permanent axial strain during a repeated load test. The flow number is found by fitting the model described in Section 13.2.2 to the permanent axial strain data using nonlinear least squares, then determining the inflection point from the second derivative of the model.

13.2.2 Permanent axial strain model:

$$\varepsilon_p = An^B + C(e^{Dn} - 1) \tag{7}$$

where:

ε_p = permanent axial strain
n = number of cycles
A, B, C, and D = fitting coefficients

13.2.3 First derivative (Permanent Axial Strain Rate)

$$\frac{d\varepsilon_p}{dn} = ABn^{B-1} + CDe^{Dn} \tag{8}$$

13.2.4 Second derivative

$$\frac{d^2\varepsilon_p}{dn^2} = AB(B-1)n^{B-2} + CD^2e^{Dn} \tag{9}$$

13.2.5 Fitting of Equation 7 shall produce a sum of squared errors between measured and fitted axial strain that is less than 0.5% when the strains are expressed in units of percent.

13.2.6 The Flow Number is reported as the cycle when the second derivative of the permanent axial strain model, Equation 9, changes from negative to positive.

13.3 Dynamic Modulus Test

13.3.1 The data produced from the dynamic modulus test at frequency ω_0 will be in the form of several arrays, one for time $[t_i]$, one for each of the $j = 1, 2, 3, \ldots m$ transducers used $[y_j]$. In the typical arrangement, there will be $m = 3$ transducers: the first transducer will be a load cell, and transducers 2 and 3 will be specimen deformation transducers. However, this approach is general and can be adapted to any number of specimen deformation transducers. The number of $i = 1, 2, 3 \ldots n$ points in each array will be equal to 500 based on the number of cycles and acquisition rate specified in Section 12.5.6. It has been assumed in this procedure that the load will be given in Newtons (N), and the deformations in millimeters (mm). The analysis has been devised to provide complex modulus in units of Pascals (1 Pa = 1 N/m^2) and phase angle in units of degrees. The general approach used here is based upon the least squares fit of a sinusoid, as described by Chapra and Canale in *Numerical Methods for Engineers* (McGraw-Hill, 1985, pp. 404-407). However, the approach used here is more rigorous, and also includes provisions for estimating drift of the sinusoid over time by including another variable in the regression function. Regression is used, rather than the Fast Fourier transform (FFT), because it is a simpler and more direct approach, which should be easier for most engineers and technicians in the paving industry to understand and apply effectively. The regression approach also lends itself to calculating standard errors and other indicators of data quality. This approach should however produce results essentially identical to those produced using FFT analysis.

13.3.2 The calculation proceeds as follows. First, the data for each transducer are centered by subtracting from the measured data the average for that transducer:

$$Y_{ji}' = Y_{ji} - \overline{Y_j} \tag{10}$$

Where:

Y_{ji}' = Centered data for transducer j at point i in data array
Y_{ji} = Raw data for transducer j at point i in data array
$\overline{Y_j}$ = Average for transducer j

13.3.3 In the second step in the procedure, the $[X'X]$ matrix is constructed as follows:

$$[X'X] = \begin{bmatrix} N & \sum_{i=1}^{n} t_i & \sum_{i=1}^{n} \cos(\omega_0 t_i) & \sum_{i=1}^{n} \sin(\omega_0 t_i) \\ \sum_{i=1}^{n} t_i & \sum_{i=1}^{n} t_i^2 & \sum_{i=1}^{n} t_i \cos(\omega_0 t_i) & \sum_{i=1}^{n} t_i \sin(\omega_0 t_i) \\ \sum_{i=1}^{n} \cos(\omega_0 t_i) & \sum_{i=1}^{n} t_i \cos(\omega_0 t_i) & \sum_{i=1}^{n} \cos^2(\omega_0 t_i) & \sum_{i=1}^{n} \cos(\omega_0 t_i)\sin(\omega_0 t_i) \\ \sum_{i=1}^{n} \sin(\omega_0 t_i) & \sum_{i=1}^{n} t_i \sin(\omega_0 t_i) & \sum_{i=1}^{n} \cos(\omega_0 t_i)\sin(\omega_0 t_i) & \sum_{i=1}^{n} \sin^2(\omega_0 t_i) \end{bmatrix} \tag{11}$$

Where N is the total number of data points, ω_0 is the frequency of the data, t is the time from the start of the data array, and the summation is carried out over all points in the data array.

13.3.4 The inverse of this matrix, $[X'X]^{-1}$, is then calculated. Then, for each transducer, the $[X'Y_j]$ array is constructed:

$$[X'Y_j] = \begin{bmatrix} \sum_{i=1}^{n} Y_{ji}' \\ \sum_{i=1}^{n} Y_{ji}' t \\ \sum_{i=1}^{n} Y_{ji}' \cos(\omega_0 t) \\ \sum_{i=1}^{n} Y_{ji}' \sin(\omega_0 t) \end{bmatrix} \tag{12}$$

Where Y_j represents the output from one of the three transducers (j=1 for the load cell, j=2 and 3 for the two deformation transducers). Again, the summation is carried out for all points in the data arrays.

13.3.5 The array representing the regression coefficients for each transducer is then calculated by multiplying the $[X'X]^{-1}$ matrix by the $[X'Y_j]$ matrix:

$$\begin{bmatrix} A_{j0} \\ A_{j1} \\ A_{j2} \\ B_{j2} \end{bmatrix} = [X'X]^{-1}[X'Y_j] \tag{13}$$

Where the regression coefficients can be used to calculate predicted values for each of the j transducers using the regression function:

$$\hat{Y}_{ji} = A_{j0} + A_{j1}t_i + A_{j2}\cos(\omega_0 t_i) + B_{j2}\sin(\omega_0 t_i) + \varepsilon_{ji} \tag{14}$$

Where $\hat{Y}_{ji}$ is the predicted value for the i^{th} point of data for the j^{th} transducer, and ε_{ji} represents the error term in the regression function.

13.3.6 From the regression coefficients, several other functions are then calculated as follows:

$$\theta_j = \arctan\left(-\frac{B_{j2}}{A_{j2}}\right) \tag{15}$$

$$|Y_j*| = \sqrt{A_{j2}^2 + B_{j2}^2} \tag{16}$$

$$\Delta Y_j = \frac{A_{j1}t_N}{|Y_j*|} \times 100\% \tag{17}$$

$$se(Y_j) = \sqrt{\frac{\sum_{i=1}^{n}\left(\hat{Y}_{ji}'-Y_{ji}'\right)^2}{n-4}}\left(\frac{100\%}{|Y_j*|}\right) \tag{18}$$

Where:

θ_j = Phase angle for transducer j, degrees
$|Y_j*|$ = Amplitude for transducer j, N for load or mm for displacement
ΔY_j = Drift for transducer j, as percent of amplitude.
t_N = Total time covered by data

$\hat{Y}_{ji}''$ = Predicted centered response for transducer j at point i, N or mm
$se(Y_j)$ = Standard error for transducer j, %
n = number of data points = 500

The calculations represented by Equations 13 through 16 are carried out for each transducer—typically the load cell, and two deformation transducers. This produces values for the phase angle, and standard errors for each transducer output. The phase angles given by Equation 13 represent absolute phase angles, that is, θ_j is an arbitrary value indicating the angle at which data collection started.

13.3.7 The phase angle of the deformation (response) relative to the load (excitation) is the important mechanical property. To calculate this phase angle, the average phase angle for the deformations must first be calculated:

$$\overline{\theta}_D = \frac{\sum_{j=2}^{m} \theta_j}{m-1} \tag{19}$$

Where $\overline{\theta}_D$ is the average absolute phase angle for the deformation transducers, and θ_j is the phase angle for each of the j = 2, 3, …, m deformation transducers. For the typical case, there are one load cell and two deformation transducers, so m = 3, and Equation 17 simply involves summing the phase angle for the two deformation transducers and dividing by two.

13.3.8 The relative phase angle at frequency ω between the deformation and the load, $\theta(\omega)$, is then calculated as follows:

$$\theta(\omega) = \overline{\theta_D} - \theta_P \tag{20}$$

Where θ_P is the absolute phase angle calculated for the load.

13.3.9 A similar set of calculations is needed to calculate the overall modulus for the material. First, the average amplitude for the deformations must be calculated:

$$\left|\overline{Y}_D{}^*\right| = \frac{\sum_{j=2}^{m} \left|Y_j{}^*\right|}{m-1} \tag{21}$$

Where $\left|\overline{Y}_D{}^*\right|$ represents the average amplitude of the deformations (mm).

13.3.10 Then, the dynamic modulus $|E^*|$ at frequency ω is calculated using the following equation:

$$|E^*(\omega)| = \frac{|Y_P^*| L_g}{|\overline{Y}_D^*| A} \tag{22}$$

Where $|E^*(\omega)|$ is in Pa, L_g is the average gage length for the deformation transducers (mm), and A is the loaded cross-sectional area for the specimen, m^2.

13.3.11 The final part of the analysis involves calculation of several factors indicative of data quality, including the average drift for the deformations, the average standard error for the deformations, and uniformity coefficients for deformation amplitude and phase:

$$\Delta\overline{Y}_D = \frac{\sum_{j=2}^{m} A_{j1} t_N}{\sum_{j=2}^{m} |Y_j^*|} \times 100\% \tag{23}$$

$$se(Y_D) = \frac{\sum_{j=2}^{m} se(Y_j)}{m-1} \tag{24}$$

$$U_A = \sqrt{\frac{\sum_{j=2}^{m} \left(|Y_j^*| - |\overline{Y}_D^*|\right)^2}{m-1}} \left(\frac{100\%}{|\overline{Y}_D^*|}\right) \tag{25}$$

$$U_\theta = \sqrt{\frac{\sum_{j=2}^{m} \left(\theta_j - \overline{\theta}_D\right)^2}{m-1}} \tag{26}$$

Where:

$\Delta\overline{Y}_D$ = Average deformation drift, as percent of average deformation amplitude
$se(Y_D)$ = Average standard error for all deformation transducers, %
U_A = Uniformity coefficient for deformation amplitude, %
U_θ = Uniformity coefficient for deformation phase, degrees

14.0 Calibration and Verification of Dynamic Performance

14.1 Prior to shipment, the complete Simple Performance Test System shall be assembled at the manufacturer's facility and calibrated. This calibration shall include calibration of the computer control and data acquisition electronics/software, static calibration of the load, deflection, specimen deformation, confining pressure and temperature measuring systems; and verification of the dynamic performance of the load and specimen deformation measuring systems.

14.2 The results of these calibrations shall be documented, certified by the manufacturer, and provided with the system documentation.

14.3 Static calibration of the load, deflection, specimen deformation, and confining pressure systems shall be performed in accordance with the following standards:

System	ASTM Standard
Load	ASTM E4
Deflection	ASTM D 6027
Specimen Deformation	ASTM D 6027
Confining Pressure	ASTM D 5720

14.4 The calibration of the temperature measuring system shall be verified over the range that the testing system will be used. A NIST traceable reference thermal detector with resolution equal to or better than the temperature sensor shall be used.

14.5 Verification of the dynamic performance of the force and specimen deformation measuring systems shall be performed by loading a proving ring or similar verification device with the specimen deformation measuring system attached. The manufacturer shall be responsible for fabricating the verification device and shall supply it with the Simple Performance Test System.

14.6 The verification device shall have a static deflection of 0.007 mm ± 0.0005 mm (0.00028 in ± 0.00002 in) at a load of 1.2 kN (0.27 kips).

14.7 The verification shall include loads of 0.5, 4.5, 8.5, and 12.5 kN (0.1, 1.0, 1.9, and 2.8 kips) at frequencies of 0.1, 1, and 10 Hz. The verification shall include measurement of load, and displacement of the verification device using the specimen deformation measuring system. All of the resulting load versus deformation data shall be within 2 percent of that determined by static loading of the verification device. The phase difference between load and displacement measurements shall be less than 1 degree.

14.8 The Simple Performance System shall include a calibration mode for subsequent annual calibration in accordance with the standards listed in Section 14.3 and the method described in 14.4. It shall also include a dynamic verification mode to perform the verification test described in Section 14.5. Access points for calibration work shall be clearly shown in the system reference manual.

15.0 Verification of Normal Operation

15.1 The manufacturer shall develop and document procedures for verification of normal operation for each of the systems listed in Section 14.3, and the dynamic performance verification discussed in Section 14.5. It is anticipated that these verification procedures will be performed by the operating technician on a frequent basis. Equipment used in the verification process shall be provided as part of the Simple Performance Test System.

16.0 Documentation

16.1 The Simple Performance Test System shall include an on-line help and documentation.

16.2 A reference manual completely documenting the Simple Performance Test System shall be provided. This manual shall include the following Chapters:

1. System Introduction.
2. Installation.
3. Loading System.
4. Confining Pressure System.
5. Environmental Chamber.
6. Control and Data Acquisition System.
7. Flow Time Test.
8. Flow Number Test.
9. Dynamic Modulus Test.
10. Calibration.
11. Verification of Dynamic Performance.
12. Verification of Normal Operation.
13. Preventative Maintenance.
14. Spare Parts List
15. Drawings.

17.0 Warranty

17.1 The Simple Performance Test System shall carry a one year on-site warranty.

Appendix A
Specification Compliance Test Methods for the Simple Performance Test System

Table A1. Summary of Specification Compliance Tests.

Item	Section	Method
Assembled Size	4.4 and 4.6	Measure
Specimen and Display Height	4.4	Measure
Component Size	4.7	Measure
Electrical Requirements	4.5 and 4.6	Documentation and trial
Air Supply Requirements	4.8	Documentation and trial
Limit Protection	4.9	Documentation and trial
Emergency Stop	4.10	Documentation, visual inspection, trial
Loading Machine Capacity	5.1	Independent force verification (See verification procedures below)
Load Control Capability	5.2 through 5.4	Trial tests on asphalt specimens and manufacturer provided dynamic verification device.
Platen Configuration	5.5	Visual
Platen Hardness	6.1	Test ASTM E10
Platen Dimensions	6.2	Measure
Platen Smoothness	6.3	Measure
Load Cell Range	7.1	Load cell data plate
Load Accuracy	7.2	Independent force verification (See verification procedures below)
Load Resolution	7.3	Independent force verification (See verification procedures below)
Configuration of Deflection Measuring System	8.1	Visual
Transducer Range	8.2	Independent deflection verification (See verification procedures below)
Transducer Resolution	8.3	Independent deflection verification (See verification procedures below)
Transducer Accuracy	8.4	Independent deflection verification (See verification procedures below)
Load Mechanism Compliance and Bending	8.5	Measure on steel specimens with various degrees of lack of parallelism
Configuration of Specimen Deformation Measuring System	9.1	Visual
Gauge Length of Specimen Deformation Measuring System	9.1	Measure
Transducer Range	9.2	Independent deflection verification (See verification procedures below)

Table A1. Summary of Specification Compliance Tests (Continued).

Item	Section	Method
Transducer Resolution	9.3	Independent deflection verification (See verification procedures below)
Transducer Accuracy	9.4	Independent deflection verification (See verification procedures below)
Specimen Deformation System Complexity	9.5	Trial
Confining Pressure Range	10.1 and 10.5	Independent pressure verification (See verification procedures below)
Confining Pressure Control	10.2	Trial tests on asphalt specimens
Confining Pressure System Configuration	10.3 and 10.4	Visual
Confining Pressure Resolution and Accuracy	10.5	Independent pressure verification (See verification procedures below)
Temperature Sensor	10.6 and 11.4	Independent temperature verification (See verification procedures below)
Specimen Installation and Equilibration Time	9.5, 10.7 and 11.3	Trial
Environmental Chamber Range and Control	11.1	Independent temperature verification (See verification procedures below)
Control System and Software	12	Trial
Data Analysis	13	Independent computations on trial test
Initial Calibration and Dynamic Performance Verification	14	Certification and independent verification
Calibration Mode	14.6	Trial
Verification of Normal Operation Procedures and Equipment	15	Review
On-line Documentation	16.1	Trial
Reference Manual	16.2	Review

INDEPENDENT VERIFICATION PROCEDURES FOR SIMPLE PERFORMANCE TESTING MACHINE

1.0 General

1.1 The testing machine shall be verified as a system with the load, deflection, specimen deformation, confining pressure, and temperature measuring systems in place and operating as in actual use.

1.2 System verification is invalid if the devices are removed and checked independently of the testing machine.

2.0 Load Measuring System Static Verification

2.1 Perform load measuring system verification in accordance with ASTM E-4.

2.2 All calibration load cells used for the load calibration shall be certified to ASTM E-74 and shall not be used below their Class A loading limits.

2.3 When performing the load verification, apply at least two verification runs of at least 5 loads throughout the range selected.

2.4 If the initial verification loads are within +/- 1% of reading, these can be applied as the "As found" values and the second set of verification forces can be used as the final values. Record return to zero values for each set of verification loads.

2.5 If the initial verification loads are found out of tolerance, calibration adjustments shall be made according to manufacturers specifications until the values are established within the ASTM E-4 recommendations. Two applications of verification loads shall then be applied to determine the acceptance criteria for repeatability according to ASTM E-4.

2.6 At no time will correction factors be utilized to corrected values that do not meet the accuracy requirements of ASTM E-4.

3.0 Deflection and Specimen Deformation Measuring System Static Verification

3.1 Perform verification of the deflection and specimen deformation measuring systems in accordance with ASTM D 6027 Test Method B.

3.2 The micrometer used shall conform to the requirements of ASTM E-83.

3.3 When performing verification of the deflection and strain measuring system, each transducer and associated electronics must be verified individually throughout it's intended range of use.

3.4 Mount the appropriate transducer in the micrometer stand and align it to prevent errors caused by angular application of measurements.

3.5 Apply at least 5 verification measurements to the transducer throughout it's range. Re-zero and repeat the verification measurements to determine repeatability.

3.6 If the readings of the first verification do not meet the specified error tolerance, perform calibration adjustments according to manufacturers specifications and repeat the applications of measurement to satisfy the error tolerances.

4.0 Confining Pressure Measuring System Verification

4.1 Perform verification of the confining pressure measuring system in accordance with ASTM D-5720.

4.2 All calibrated pressure standards shall meet the requirements of ASTM D-5720.

4.3 Attach the pressure transducer to the pressure standardizing device.

4.4 Apply at least 5 verification pressures to the device throughout it's range recording each value. Determine if the verification readings fall within +/- 1 % of the value applied.

4.5 If the readings are within tolerance, apply a second set of readings to determine repeatability. Record the return to zero values for each set of verification pressures.

4.6 If readings are beyond tolerance, adjust the device according to manufacturers specifications and repeat the dual applications of pressure as described above to complete verification.

5.0 Temperature Measuring System Verification

5.1 Verification of the temperature measuring system will be performed using a using a NIST traceable reference thermal detector that is readable and accurate to 0.1 °C.

5.2 A rubber band or O-ring will be used to fasten the reference thermal detector to the system temperature sensor.

5.3 Comparisons of the temperature from the reference thermal detector and the system temperature will be made at 6 temperatures over the operating range of the environmental chamber.

5.4 Once equilibrium is obtained at each temperature setting, record the temperature of the reference thermal detector and the system temperature sensor.

5.5 Also check stability of the environmental chamber by noting the maximum and minimum temperatures during cycling at the set temperature.

6.0 Dynamic Performance Verification

6.1 The verification of the dynamic performance of the equipment will be performed after static verification of the system.

6.2 The dynamic performance verification will be performed using the verification device provided with the system by the manufacturer.

6.3 First, the verification device will be loaded statically to obtain the static relationship between force and displacement. This relationship will be compared to that provided by the manufacturer in the system documentation.

6.4 The verification device will then be used to simulate dynamic modulus test conditions. Load and displacement data will be collected on the verification device using loads of 0.5, 4.5, 8.5, and 12.5 kN (0.1, 1.0, 1.9, and 2.8 kips) at frequencies of 0.1, 1, and 10 Hz. The peak load and displacements will be determined and plotted along with the static data. The data shall plot within +/- 2 percent of the static force displacement relationship.

6.5 The verification device will also be used to check the phase difference between the load and specimen deformation measuring system. The phase difference shall be less than 1 degree.

Appendix B

Minimum Testing Program For Comparison of a Non-Standard Specimen Deformation Measuring System to the Standard Specimen Deformation Measuring System

NCHRP 9-29 Equipment Specification for the Simple Performance Test System
Version 3.0
October 16, 2007

1.0 Summary

1.1 This Annex describes the minimum testing, analysis, and reporting required to demonstrate that a nonstandard specimen deformation measuring system produces the same dynamic modulus and phase angle results as the standard glued gauge point system specified in Section 9.0 of the these specifications.

1.2 The basic approach is to collect dynamic modulus and phase angle data on a single mixture using the simple performance test system with the standard glued gauge point system and the proposed alternative. Standard statistical hypothesis tests are then performed on the resulting data to verify that there is no difference in the mean and variance of the dynamic modulus and phase angles measured with the two systems.

1.3 To provide data over a wide range of modulus and phase angles, the testing will be performed for the conditions listed in Table B-1.

Table B-1. Testing Conditions.

Temperature, °C (°F)	Confinement, kPa (psi)	Frequencies, Hz
25 (77)	Unconfined	10, 1, and 0.1
45 (113)	Unconfined	10, 1, and 0.1
45 (113)	140 (20 psi)	10, 1, and 0.1

1.4 Tests on twelve independent specimens will be performed with each specimen deformation measuring system. Thus a total of 24 specimens will be fabricated and tested.

2.0 Test Specimens

2.1 The testing shall be performed on simple performance test specimens meeting the dimensional tolerances of Section 3.0 of these specifications.

2.2 Use a coarse-graded 19.0 mm nominal maximum aggregate size mixture with a PG 64-22 binder. The mixture shall meet the requirements of AASHTO MP2 for a surface course with a design traffic level of 10 to 30 million ESALs. The percent passing the 2.36 mm sieve shall be less than 35 percent. Prepare test specimens at the optimum asphalt content determined in accordance with AASHTO PP28 for a traffic level of 3 to <30 million ESALs. Mixtures shall be short term oven aged for 2 hours at the compaction temperature in accordance with AASHTO R30.

2.3 Prepare 24 test specimens within the air void content range of 3.5 to 4.5 percent. Rank the test specimens based on air void content. Group the test specimens into two subsets such that the average and standard deviation of the air void contents are approximately equal.

3.0 Dynamic Modulus Testing

3.1 Perform the dynamic modulus testing with the Simple Performance Test System in accordance with the Standard Test Method for Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Simple Performance Test. Repeat tests as needed to ensure that the data quality indicators are within their allowable ranges.

3.2 Perform the testing in blocks of three specimens in the order listed in Table B-2. Plan the testing such that all testing in a block will be completed on the same day.

Table B-2. Block Order Testing.

Block	Temperature, °C (°F)	Confinement, kPa (psi)	Specimen Deformation System
1	25 (77)	0	Standard
			Proposed
2	25 (77)	0	Standard
			Proposed
3	25 (77)	0	Standard
			Proposed
4	25 (77)	0	Standard
			Proposed
5	45 (113)	140 (20)	Standard
			Proposed
6	45 (113)	140 (20)	Standard
			Proposed
7	45 (113)	140 (20)	Standard
			Proposed
8	45 (113)	140 (20)	Standard
			Proposed
9	45 (113)	0	Standard
			Proposed
10	45 (113)	0	Standard
			Proposed
11	45 (113)	0	Standard
			Proposed
12	45 (113)	0	Standard
			Proposed

4.0 Data Analysis

4.1 For each combination of device, temperature, confining pressure, and frequency, prepare summary tables listing the measured dynamic modulus and phase angles, and the data quality indicators. A total of 18 summary tables, 9 for each measuring system will be prepared. Each of these summary tables will represent a specific combination of temperature, confining pressure, and frequency of loading.

4.2 For each summary table, compute the mean and variance of the dynamic modulus and phase angle measurements using Equations B-1 and B-2.

$$\bar{y} = \frac{\sum_{i=1}^{12} y_i}{12} \qquad \text{(B1)}$$

$$s^2 = \frac{\sum_{i=1}^{12} (y_i - \bar{y})^2}{11} \qquad \text{(B2)}$$

where:

$\bar{y}$ = sample mean
s^2 = sample variance
y_i = measured values

5.0 Statistical Hypothesis Testing

5.1 For each combination of temperature, confining pressure, and frequency of loading test the equality of variances between the standard specimen deformation system and the proposed specimen deformation measuring system using the F-test described below. In the description below, the subscript s refers to the standard system and the subscript p refers to the proposed system.

Null Hypothesis:

Variance of proposed system equals that of standard system, $\sigma_p^2 = \sigma_s^2$

Alternative Hypothesis:

Variance of proposed system is greater than that of standard system, $\sigma_p^2 > \sigma_s^2$

Test Statistic:

$$F = \frac{s_p^2}{s_s^2}$$

where

s_p^2 = computed sample variance for the proposed system
s_s^2 = computed sample variance for the standard system

Region of Rejection:

For the sample sizes specified, the test statistic must be less than 2.82 to conclude that the variances are equal.

5.2 Summarize the resulting test statistics for dynamic modulus and phase angle.

5.3 If the results conclude the variance is greater for the proposed measuring for any of the combinations of temperature, confinement, and loading frequency tested, then the proposed measuring system is unacceptable.

5.4 For combinations of temperature, confinement, and loading frequency where equality of variances is confirmed by the hypothesis test in Item 5.1, test the equality of means between the standard specimen deformation system and the proposed specimen deformation measuring system using the t-test described below. In the description below, the subscript *s* refers to the standard system and the subscript *p* refers to the proposed system.

Null Hypothesis:

Mean from the proposed system equals that from the standard system, $\mu_p^2 = \mu_s^2$

Alternative Hypothesis:

Mean from the proposed system is not equal to that from the standard system, $\mu_p^2 \neq \mu_s^2$

Test Statistic:

$$t = \frac{(\bar{y}_p - \bar{y}_s)}{\frac{n}{\sqrt{6}}}$$

where:

$$s = \sqrt{\frac{s_p^2 + s_s^2}{2}}$$

$\bar{y}_p$ = computed sample mean from the proposed system
$\bar{y}_s$ = computed sample mean from the standard system
s_p^2 = computed sample variance for the proposed system
s_s^2 = computed sample variance for the standard system

Region of Rejection:
For the sample sizes specified, the absolute value of the test statistic must be less than 2.07 to conclude that the means are equal.

5.5 Summarize the resulting test statistics for dynamic modulus and phase angle.

5.6 If the results conclude the means are not equal for any of the combinations of temperature, confinement, and loading frequency tested, then the proposed measuring system is unacceptable.

6.0 Report

6.1 Design data for the mixture used in the evaluation.

6.2 Air void contents for individual specimens and the average and standard deviations of the air void contents for the two subsets.

6.3 Tabular chronological summary of the block testing showing starting date and time and completion date and time for each block.

6.4 Summary tables of dynamic modulus, phase angle, and data quality indicators for each combination of temperature, confining pressure, and loading frequency for the two measuring systems.

6.5 Summary tables of the mean and variance of the dynamic modulus and phase angle for each combination of temperature, confining pressure, and loading frequency for the two measuring systems.

6.6 Summary tables of the hypothesis tests for the variance and mean of the dynamic modulus and phase angle for each combination of temperature, confining pressure, and loading frequency.

6.7 Conclusions concerning the acceptability of the proposed measuring system.